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Externally Fired Combined Cycle Demonstration

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DISCLAIMER

2.4 Externally Fired Combined Cycle Demonstration

CONTRACT INFORMATION

Contract Number	DE-AC21-94MC31327
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OBJECTIVES

Externally Fired Combined Cycles (EFCCs) can increase the amount of electricity produced from ash bearing fuels up to 40%, with overall powerplant efficiencies in excess of 45%. Achieving such high efficiencies requires high temperature - high pressure air heaters capable of driving modern gas turbines from gas streams containing the products of coal combustion.

A pilot plant has been constructed in Kennebunk, Maine to provide proof of concept and evaluation of system components. Tests using pulverized Western Pennsylvania bituminous coal have been carried out since April, 1995.

The ceramic air heater extracts energy from the products of coal combustion to power a gas turbine. This air heater has operated at gas inlet temperatures over 1095°C (2000°F) and pressures over 7.0 atm (100 PSI) without damage to the ceramic tube string components. Stable gas turbine operation has been achieved with energy input from the air heater and a supplementary gas fired combustor.

Efforts are underway to fire the cycle on coal only, and to increase the duration of the test runs. Air heater improvements are being implemented and evaluated. These improvements include installation of a second pass of ceramic tubes and evaluation of corrosion resistant coatings on the ceramic tubes.

BACKGROUND INFORMATION

The Externally Fired Combined Cycle (EFCC) is an old concept. Essentially, an air heater fired on an ash bearing fuel that cannot be burned directly in the gas turbine energizes the cycle.

Use of the air heater means that the gas turbine does not come in contact with the products of combustion. In other words, the air heater protects the gas turbine from corrosion and erosion by chemicals and particulate produced by the combustion of the fuel.

The gas turbine compressor provides pressurized air to the tube-side of the ceramic air heater. Heat transferred from the hot combustion gases flowing through the shell-side of the air heater raises the temperature of the air to the desired gas turbine inlet temperature.

High pressure piping conducts this heated air to the turbine, where it expands, providing power to drive the electric generator and the gas turbine compressor.

The hot exhaust air from the turbine is used as combustion air in the coal burner.

The air heater's shell-side exit gas generates steam for a bottoming cycle.

EFCC studies have been performed since the 1930s, and there is a history of applications using low rank fuels and metallic heat exchangers dating to the 1950s [1, 2, 3].

A state of the art gas turbine, however, requires inlet temperatures in excess of the temperatures that can be achieved with metallic heat exchangers.

In 1971, Hague International began a series of experiments with ceramic materials that resulted in the construction of a ceramic tubular heat exchanger of novel design.

Hague's ceramic tubular heat exchangers have been in commercial operation since June, 1978. Gas inlet temperatures have ranged up to 1540°C (2800°F) at tube-side pressures averaging 0.3 atm (4 psi).

Such low pressure units have been installed in ferrous and non-ferrous secondary metals industries in North America and Japan, accumulating several million hours of successful operation in a variety of corrosive high temperature environments [4, 5, 6, 7, 8, 9].

In addition, low pressure ceramic tubular heat exchangers were exposed to the products of combustion of coal slurries to investigate the effects of ash.

These preliminary investigations indicated the need for an upstream ash collection system. Further and ongoing evaluation of the available ceramic materials for use in the air heater dictates that special consideration be given to corrosion resistance when operating on coal [10, 11, 12].

PROJECT DESCRIPTION

Phase 1 of the project, beginning in 1987, investigated whether the ceramic materials then available for use in the air heater would withstand the corrosive environment produced by the combustion of coal up to the desired temperature of 1200°C (2200°F). Phase 1 of the project also evaluated, in a preliminary way, means of preventing the fouling of the air heater by fly ash. This experimental work was deemed successful by Stone & Webster Engineering Company [6, 13, 14].

Phase 2 of the program, initiated in 1990, built a 7MW thermal input pilot plant under the auspices of a cooperative agreement with the U.S. Department of Energy Morgantown Energy Technology Center (DOE METC). This work was funded by a consortium of electric utilities, utility organizations, industrial organizations, state agencies, international entities, and DOE METC.

During 1995 the pilot plant is intended to function as a proof of concept facility operating under conditions that simulate the conditions intended for the DOE Clean Coal Technology Round V demonstration plant [6, 15].

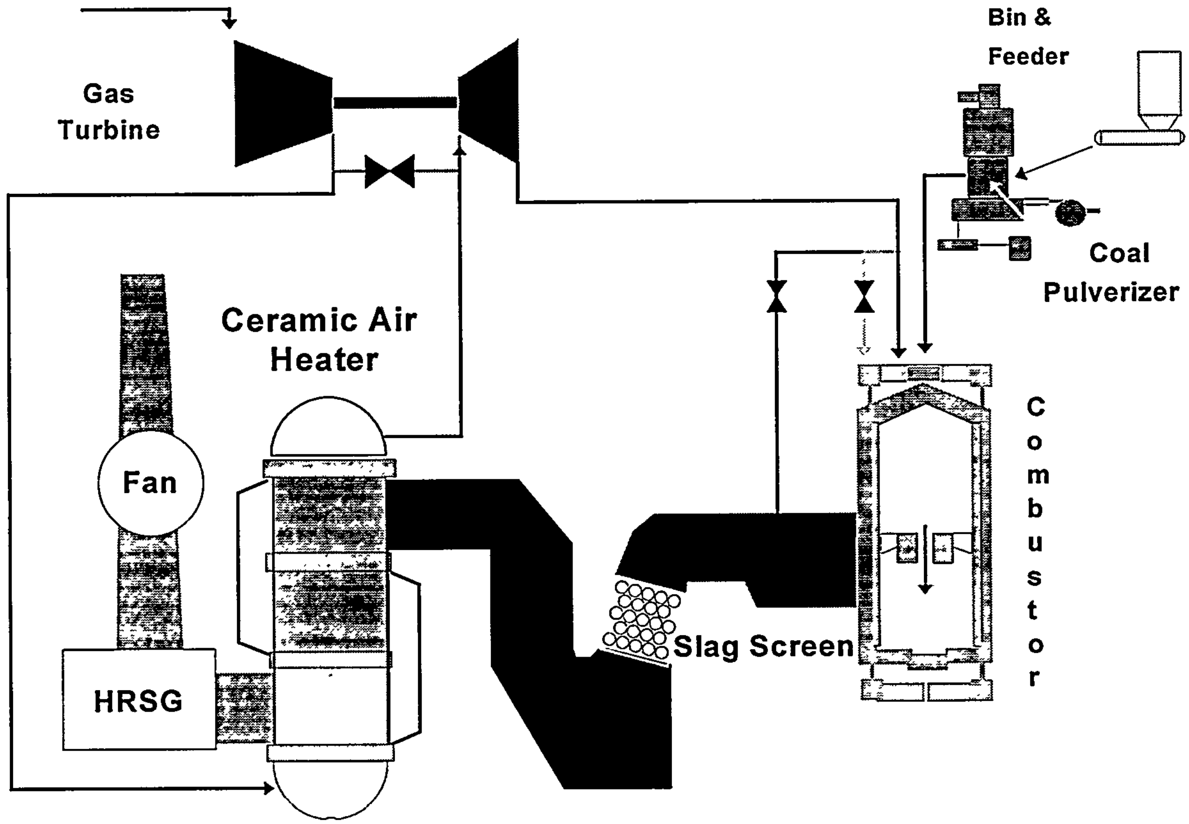

Figure 1: Kennebunk Test Facility (KTF) Schematic

RESULTS

Construction of the Kennebunk Test Facility has been completed. This facility now incorporates all the major elements of an EFCC plant, with the exception of a steam turbine, omitted for reasons of economy. The steam generated is simply discharged to atmosphere.

Pennsylvania bituminous coal is fed through a weigh belt and a pulverizer before delivery to the combustor. The products of combustion pass through a slag screen before introduction to the air heater. The air heater is a three pass shell and tube heat exchanger that accepts high pressure tube-side air from the gas turbine compressor.

Pressurized heated air is delivered to the gas turbine. Gas turbine exhaust is used as combustion air to burn the coal. Heat exchanger shell-side exit flows to a steam generator.

A Garrett IE31-800 gas turbine with a rating of 500 KW has been installed. The test facility can accommodate gas turbines rated up to 2 MW with some modifications.

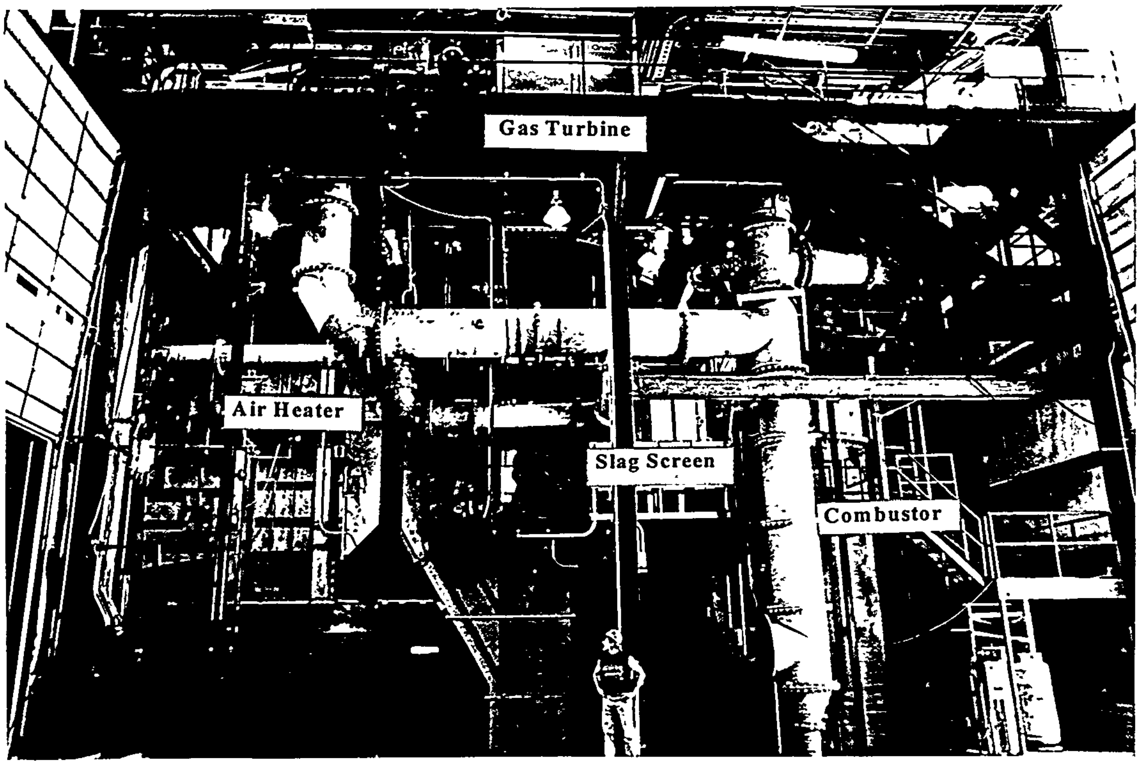

Figure 2: KTF Combustor, Slag Screen, Ceramic Air Heater, Gas Turbine

The coal combustor is staged to reduce NO_x emissions. A Foster Wheeler Controlled Flow/Split Flame low NO_x burner downfires into a cylindrical combustion chamber with the primary stage directly atop the secondary stage.

The total height of the combustor, including the burner, is approximately 12.1 meters (40 feet), and the outer diameter of the cylindrical casing is approximately 3.96 meters (13 feet). A slag tap is located at the base of the combustor.

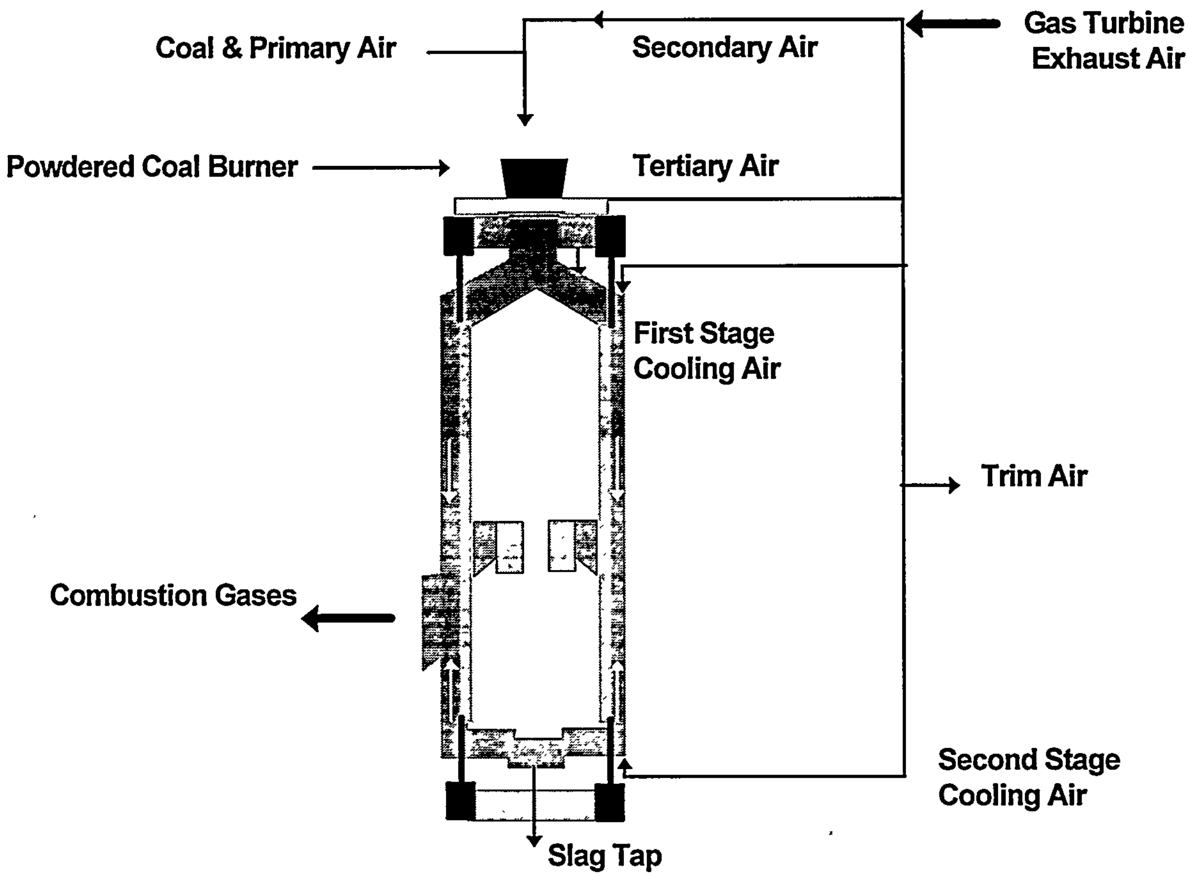

Figure 3: Combustor Schematic

Products of combustion exit the combustor and enter the slag screen at a high velocity.

The slag screen is an impact separator made up of ceramic rods. The slag screen is designed to be self cleaning.

After exiting the slag screen, the products of combustion flow to the air heater, passing over the air heater tubes at velocities approximately half the velocities in the slag screen. This assures minimal particle accumulation on the air heater tubes. These deposits can be removed by conventional means, such as soot blowers.

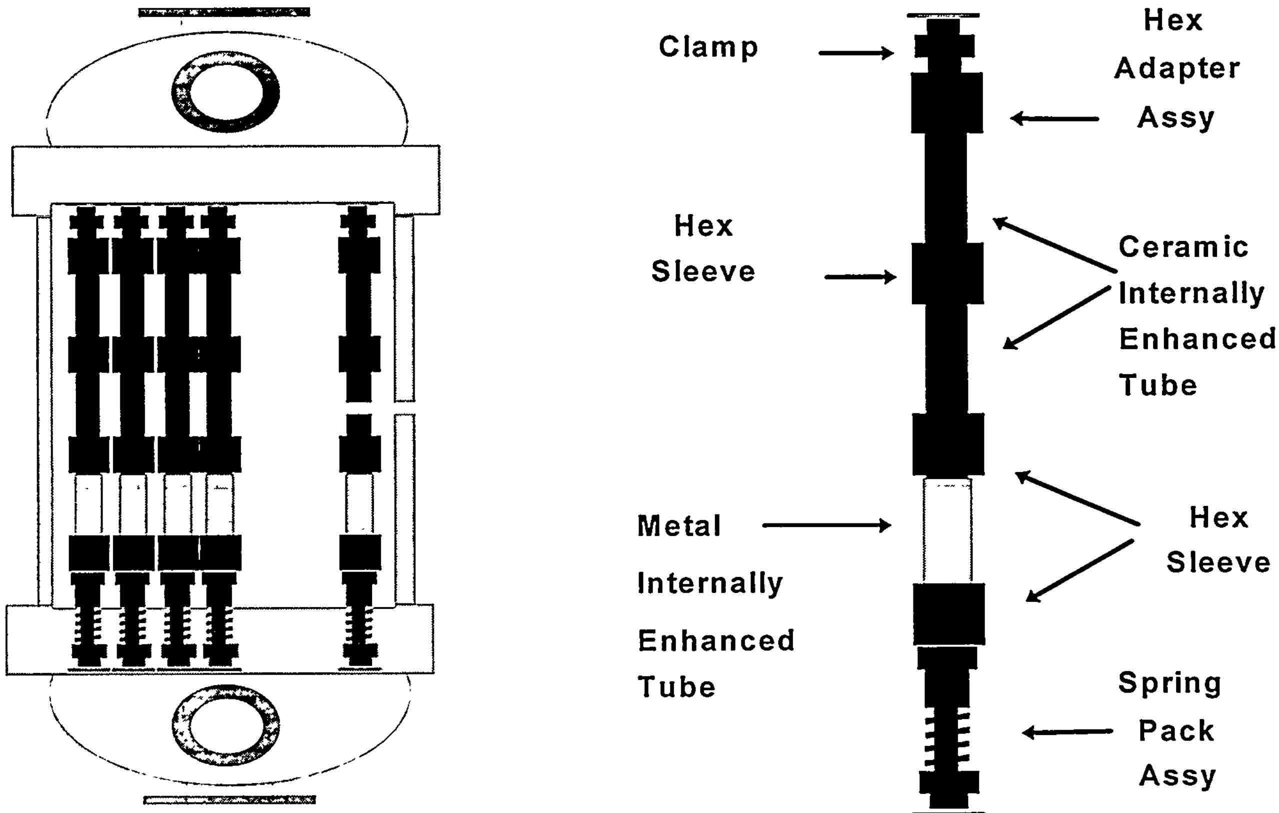

Figure 4: Air Heater Schematic

The air heater is the enabling technology for Externally Fired Combined Cycles [6, 16, 17]. The air heater at the Kennebunk Test Facility is made up of three passes of tubes, with 72 tubes in each pass.

Compressor discharge from the gas turbine flows inside the tube strings. The tubes are held in place by spring pack assemblies and hexagonal adapters.

Gasketed ball and socket joints allow independent movement of each component in the tube string as may be required to accommodate thermal distortion of the assembly. The ball and socket joints allow a relatively high degree of angular misalignment without leakage.

The spring pack assemblies hold the tube strings under compression. The spring pack assemblies are located on the cold end of the tube string, outside of the combustion gas path, so that these components are not exposed to temperatures above 205°C (400°F).

Hexagonal adapters hold tube strings in place, and allow for differences in thermal expansion of individual tube strings.

These hexagonal pieces fit together in honeycomb fashion to form thermal barriers separating the shell-side flow of one pass from another pass, and provide refractory walls to protect the metal components of the air heater's plena.

Several types of silicon carbide ceramic tubes have been successfully used in the high pressure air heater at the Kennebunk Test Facility. Hague International has developed proprietary methods to prevent the sequential failure of brittle ceramic tubes.

In its present configuration, the heat exchanger has one pass of ceramic tubes, for exposure to the hottest combustion gases, and two passes of metallic tubes. A second pass of ceramic tubes is to be installed to increase the delivery temperature to the gas turbine during late summer, 1995.

Metal alloys can be used in the low temperature end of the heat exchanger (<760°C, <1400°F) for cost effectiveness.

The first coal-fired demonstration was to check out the coal handling and coal combustion systems, pressurize the air heater, and evaluate the performance of a partial pass of ceramic tubes. This was completed in March, 1995.

The second coal-fired demonstration at the Kennebunk Test Facility took place April 25-30, 1995. The first pass of the air heater consisted of 72 ceramic tubes. The remainder of the air heater was fitted with metal tubes. The goal of this demonstration was to extend coal-fired operations, run in EFCC mode without preheat to the combustor, and to integrate turbine controls. This demonstration was cut short when leaks developed in gaskets outside of the combustion gas path. These gaskets were replaced, and the facility is to be back on line in July, 1995.

Gas inlet temperatures to the air heater in excess of 1095°C (2000°F) and tube-side pressures in excess of 7.0 atm (100 psi) have been demonstrated.

Post demonstration analysis indicates that there has been no damage to the ceramic tubes during operation to date.

Slag screen performance has been as expected, even at low combustion gas velocities. Minor deposits of friable ash have been found in low gas velocity sections of the air heater. Previous experience with low pressure ceramic tubular heat exchangers indicates that such friable deposits can be removed with conventional sootblowers [7, 8, 10, 12].

Preliminary emissions testing has been encouraging, but more extended testing will be required before reliable data can be published.

FUTURE WORK

Future work includes further EFCC demonstrations at the Kennebunk Test Facility. Demonstrations of up to 100 hours of continuous coal-fired turbine operation, without supplementary fuel, are planned for early fall. Longer runs are necessary to confirm, among other things, measurements of slag screen performance and NO_x emissions.

To increase the air temperature to the turbine, two ceramic passes will be installed in the air heater.

Component evaluation will be performed after each run, with component and system improvements being made on the basis of post run analyses. Special attention will be paid to heat transfer, deposit accumulation, and corrosion resistance.

Ceramic materials continue to be evaluated. Promising tube joining techniques that would permit the fabrication of tubes 4.2m (14 feet) and longer are being pursued with government laboratories, independent laboratories, and vendors of ceramic components. The Idaho National Engineering Laboratory has provided samples of joined SiC tubing of the diameter to be used in a full scale ceramic air heater. Tests performed with flat samples indicated that the joint is at least as strong as the bulk silicon carbide. In principle there is no limit to the length of tubes which can be joined.

To reduce tube corrosion, tube coating technologies are being investigated with government laboratories, independent laboratories, and commercial vendors. The long term goal is to obtain a coating that will withstand 20,000 hours of operation in an environment of coal combustion products at 1370°C (2700°F). Ceramic oxide coatings applied to SiC tubes have been repeatedly cycled to 1100°C (2020°F) without adverse effect to the coating. There are no signs of spalling or lamination, and X-ray diffraction analyses of tested coatings indicate no change in the phase composition of the coatings or the substrate. It remains to be evaluated how resistant coatings are to coal combustion products for prolonged periods of time at operating temperature.

The United States Department of Energy has estimated a commercial potential for EFCC technology of 24GWe by 2010 [15].

Successful commercialization of EFCC technology will require demonstration of the technology in a commercial power generating environment, which is currently planned [6, 15].

EFCCs offer technical and economic advantages: no hot gas cleanup or novel chemical processes are required; and repowering and upgrading existing steam turbine power plants with EFCC technology makes maximum use of existing facilities.

Competition for EFCC is now and is expected to remain gas-fired combined cycles, as long as natural gas is readily available at low prices.

Repowering is an attractive initial focus of commercialization because there are approximately 500 coal-fired steam installations that are EFCC candidates in the United States. The EFCC concept is expected to have a major impact on repowering of existing coal-fired steam turbine power plants well into the next century.

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